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Intrinsic Charm Flavor and Helicity Content in the Proton*

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Contributions to the quark flavor and spin observables from the intrinsic charm in the proton are discussed in the SU(4) quark meson fluctuation model. Our results suggest that the probability of finding the intrinsic charm in the proton is less than 1%. The intrinsic charm helicity is small and negative, $\Delta c \simeq -(0.003 \sim 0.015)$. The fraction of the total quark helicity carried by the intrinsic charm is less than 2%, and $c_\uparrow/c_\downarrow = 35/67$.

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1. Introduction

The *intrinsic* heavy quark component in the nucleon wave function has been suggested by many authors long time ago [1, 2]. This component, created from the quantum fluctuations associated with the bound state hadron dynamics, exists in the hadron over a long time independent of any external probe momentum. The probability of finding the intrinsic heavy quarks in the hadron is completely determined by nonperturbative mechanisms. On the other hand, the *extrinsic* heavy quarks are created on a short time scale in association with a large transverse momentum reaction and their distributions can be derived from QCD bremsstrahlung and pair production processes, which lead to standard QCD evolution. At the scale m_c^2 or lower, we only need to consider the intrinsic charm (IC) contribution. An interesting question is what will be the size of the IC contribution to the flavor and spin observables of the proton if the IC does exist. Since there is no direct experimental data of the IC content, one has to resort to the nucleon models (see e.g. [2, 3]) or combination of using the model and analysing the DIS data to obtain some information of the IC contribution (see e.g. [4]).

Although the SU(3) chiral quark model with symmetry breaking provides a useful nonperturbative tool in describing the quark spin, flavor [5] and orbital structure [6], the model is quite *unnatural* from the point of view of the standard model. According to the symmetric GIM model [7], one should deal with the weak axial current in the framework of SU(4) symmetry. It implies that the charm quark should be included in determining the spin, flavor and orbital structure of the nucleon. In an earlier report [8], the author has suggested an extended SU(4) version of the chiral quark model and presented some preliminary results. In the chiral quark model or more precisely the quark meson fluctuation model (some earlier works on this model see e.g. [9]), the nucleon structure is determined by its valence quark configuration and all possible quantum fluctuations of valence quarks into quarks plus mesons. In the SU(4) model, the charm or anti-charm quarks reside in the charmed mesons which are created by nonperturbative quantum quark-meson fluctuations. Hence these charm or anticharm quarks are essentially *intrinsic*.

2. SU(4) model with symmetry breaking

In the framework of SU(4) quark model, there are sixteen pseudoscalar mesons, a 15-plet and a singlet. In this paper, the contribution of the SU(4) singlet will be neglected. The effective Lagrangian describing interaction between quarks and the mesons is

$$L_I = g_{15}\bar{q}\begin{pmatrix} G_u^0 & \pi^+ & \sqrt{\epsilon}K^+ & \sqrt{\epsilon_c}\bar{D}^0 \\ \pi^- & G_d^0 & \sqrt{\epsilon}K^0 & \sqrt{\epsilon_c}D^- \\ \sqrt{\epsilon}K^- & \sqrt{\epsilon}\bar{K}^0 & G_s^0 & \sqrt{\epsilon_c}D_s^- \\ \sqrt{\epsilon_c}D^0 & \sqrt{\epsilon_c}D^+ & \sqrt{\epsilon_c}D_s^+ & G_c^0 \end{pmatrix} q, \tag{1}$$

where $D^+ = (c\bar{d})$, $D^- = (\bar{c}d)$, $D^0 = (c\bar{u})$, $\bar{D}^0 = (\bar{c}u)$, $D_s^+ = (c\bar{s})$, and $D_s^- = (\bar{c}s)$. The neutral charge components $G_{u(d)}^0$ and $G_{s,c}^0$ are defined as

$$G_{u(d)}^0 = +(-)\frac{\pi^0}{\sqrt{2}} + \sqrt{\epsilon_\eta}\frac{\eta^0}{\sqrt{6}} + \zeta'\frac{\eta'^0}{4\sqrt{3}} - \sqrt{\epsilon_c}\frac{\eta_c^0}{4} \tag{2}$$

$$G_s^0 = -\sqrt{\epsilon_\eta}\frac{2\eta^0}{\sqrt{6}} + \zeta'\frac{\eta'^0}{4\sqrt{3}} - \sqrt{\epsilon_c}\frac{\eta_c^0}{4} \tag{3}$$

$$G_c^0 = -\zeta'\frac{3\eta'^0}{4\sqrt{3}} + \sqrt{\epsilon_c}\frac{3\eta_c^0}{4} \tag{4}$$

with $\pi^0 = (u\bar{u} - d\bar{d})/\sqrt{2}$, $\eta^0 = (u\bar{u} + d\bar{d} - 2s\bar{s})/\sqrt{6}$, $\eta'^0 = (u\bar{u} + d\bar{d} + s\bar{s})/\sqrt{3}$, and $\eta_c^0 = (c\bar{c})$. Similar to the SU(3) case, we define $a \equiv |g_{15}|^2$, which denotes the transition probability of splitting $u(d) \rightarrow d(u) + \pi^{+(-)}$. Hence ϵa,

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$\epsilon_\eta a$ and $\epsilon_c a$ denote the probabilities of splittings $u(d) \to s + K^{-(0)}$, $u(d) \to u(d) + \eta^{(0)}$ and $u(d) \to c + \bar{D}^0(D^-)$ respectively. If the breaking effects are dominated by the mass differences, we expect $0 < \epsilon_c < \epsilon \simeq \epsilon_\eta < 1$.

In addition to the allowed fluctuations discussed in the SU(3) case, a valence quark (u or d in the proton) is now allowed to split up or fluctuate to a recoil charm quark and a charmed meson. For example, a valence u-quark with spin-up, the allowed fluctuations are

$$u_\uparrow \to d_\downarrow + \pi^+, \quad u_\uparrow \to s_\downarrow + K^+, \quad u_\uparrow \to u_\downarrow + G_u^0, \quad (5)$$
$$u_\uparrow \to c_\downarrow + \bar{D}^0, \quad (6)$$
$$u_\uparrow \to u_\uparrow. \quad (7)$$

Similarly, one can list the allowed fluctuations for $u_\downarrow$, $d_\uparrow$, $d_\downarrow$, $s_\uparrow$, and $s_\downarrow$. Similar to the SU(3) [6] case, the spin-up and spin-down quark or antiquark contents in the proton, up to first order of the quantum fluctuation, can be calculated.

3. Quark flavor and spin contents

We note that the quark *flips* its spin in the splitting processes $q_{\uparrow,(\downarrow)} \to q_{\downarrow,(\uparrow)}$+meson, i.e. processes in (5) and (6), but not in $u_\uparrow \to u_\uparrow$. The quark helicity non-flip contributions in the splitting processes (5) and (6) are neglected, which is the basic assumption in the model.

3.a. Flavor content in the nucleon

The quark and antiquark flavor contents are

$$u = 2 + \bar{u}, \quad d = 1 + \bar{d}, \quad s = 0 + \bar{s}, \quad c = 0 + \bar{c}, \quad (8)$$

$$\bar{u} = a[1+\tilde{A}^2+2(1-\tilde{A})^2], \quad \bar{d} = a[2(1+\tilde{A}^2)+(1-\tilde{A})^2], \quad (9)$$

$$\bar{s} = 3a[\epsilon + \tilde{B}^2], \quad \bar{c} = 3a[\epsilon_c + \tilde{D}^2], \quad (10)$$

where $\tilde{A}$, $\tilde{B}$, $\tilde{C}$, and $\tilde{D}$ are defined similar to those in the SU(3) case. From (9), one obtains

$$\bar{u}/\bar{d} = 1 - 6\tilde{A}/[(3\tilde{A}-1)^2 + 8], \quad (11)$$

and

$$\bar{d} - \bar{u} = 2a\tilde{A}. \quad (12)$$

Similarly, one can obtain $2\bar{c}/(\bar{u}+\bar{d})$, $2\bar{c}/(u+d)$, $2\bar{c}/\sum(q+\bar{q})$ and other flavor observables. One remark should be made here. Defining the ratio, $r \equiv \bar{u}/\bar{d}$, we obtain, from Eqs. (11) and (12),

$$1/2 \le \bar{u}/\bar{d} \le 5/4, \quad (13)$$

which seems to be consistent with the experimental data shown in Table I.

3.b. Helicity content in the nucleon

Similarly, we obtain

$$\Delta u = (4/3)[1 - a(\epsilon + \epsilon_c + 2f)] - a, \quad \Delta c = -a\epsilon_c, \quad (14)$$

$$\Delta d = (-1/3)[1 - a(\epsilon+\epsilon_c+2f)] - a, \quad \Delta s = -a\epsilon_s, \quad (15)$$

(where f is generalization of $f_{SU(3)}$ defined in [5]) and

$$\Delta\bar{q} = 0, \qquad (\bar{q} = \bar{u}, \bar{d}, \bar{s}, \bar{c}). \quad (16)$$

Several remarks are in order.

- In the splitting process $u_{\uparrow(\downarrow)} \to c_{\downarrow(\uparrow)} + \bar{D}^0$, the anticharm resides only in the charmed meson, e.g. $\bar{D}^0(\bar{c}, u)$. The probabilities of finding $\bar{c}_\uparrow$ and $\bar{c}_\downarrow$ are equal in the spinless charmed meson. Therefore $\Delta\bar{c} = 0$. Similar discussion in the SU(3) case has led to $\Delta\bar{q} = 0$ for $\bar{q} = \bar{u}, \bar{d}, \bar{s}$. The DIS data [10] seems to support this prediction.

- The charm quark helicity Δc is *nonzero* as far as ϵ_c is nonzero. Analogous to the strange quark helicity, Δc is definitely *negative*, because in the splitting processes, $u_{\uparrow(\downarrow)} \to c_{\downarrow(\uparrow)} + \bar{D}^0$ and $d_{\uparrow(\downarrow)} \to c_{\downarrow(\uparrow)} + D^-$, more $c_\downarrow$ is created than $c_\uparrow$, because of the probability of finding the valence u-quark in the zeroth approximation, $n_p^{(0)}(u_\uparrow)$, is dominant.

- From (10) and (14), using $\tilde{D}^2 = \epsilon_c/16$, one can see that the ratio

$$\Delta c/\bar{c} = -16/51 \quad (17)$$

is a constant, which *does not depend on* any splitting parameters. This is a special prediction for the charm flavor in the SU(4) quark meson model. Combining (17) and (16), one obtains $c_\uparrow/c_\downarrow = 35/67$. For the strangeness, if $\zeta' = 0$, one has similar result, i.e. $\Delta s/\bar{s} = -3/10$ is also a constant and $s_\uparrow/s_\downarrow = 7/13$.

4. Numerical results and discussion.

Since the effect arising from splitting (6) is smaller than those from (5), we expect the values of parameters a and ϵ in SU(4) should be very close to those used in SU(3) version, where $a = 0.145$, $\epsilon = 0.46$. We choose $a = 0.143$, $\epsilon = 0.454$, and leave ϵ_c as a *variable*, then the quark flavor and helicity contents can be expressed as functions of ϵ_c. To determine the value of ϵ_c, we use the low energy hyperon β-decay data [11], $\Delta_3 = 1.2670 \pm 0.0035$. We find

$$\epsilon_c \simeq 0.06 \pm 0.04. \quad (18)$$

Using only *three* parameters, $\{a, \epsilon, \epsilon_c\}$, the flavor and spin observables are calculated and listed in Table I and Table II respectively. For comparison, we also list the existing data and results given by SU(3) description and other models or analyses. One can see that the model satisfactorily describes almost all the existing data and also gives some new predictions. Several remarks are in order:

- The theoretical uncertainties shown in the quantities in Tables I and II arise from the uncertainty of ϵ_c in (11). If the observable does not depend on ϵ_c, such as $\bar{d}-\bar{u}$, $\bar{d}/\bar{u}$, $2\bar{s}/(\bar{u}+\bar{d})$, etc., there is no uncertainty for them. Two special quantities $\Delta c/\bar{c}$ and $\Delta s/\bar{s}$ are also independent of ϵ_c (see Table II).

- The SU(4) version predicts the IC component in the proton, $2\bar{c}/\sum(q+\bar{q})\simeq 1\%$, which agrees with the predictions given in [2] and [4e], and is also close to the those given in [3a], [3d] and [4f]. We note that the IC component is almost one order of magnitude smaller than the intrinsic strange component $2\bar{s}/\sum(q+\bar{q})$.

- Using similar approach given in a previous work (see Eq. (3.6) in [9c], we can show that $<2x\bar{c}(x)>/<\sum[xq(x)+x\bar{q}(x)]>$ is smaller than $2\bar{c}/\sum(q+\bar{q})$, where $q(\bar{q})\equiv\int_0^1 dxq(\bar{q})(x)$, and $<xq(\bar{q})(x)>\equiv\int_0^1 dxxq(\bar{q})(x)$. It implies that the fraction of the total quark momentum carried by the charm and anticharm quarks is less than 1%.

- The prediction of intrinsic charm polarization, $\Delta c\simeq -0.009\pm 0.006$ is close to the result $\Delta c=-0.020\pm 0.005$ given in the instanton QCD vacuum model [3c]. Our result is smaller than that given in [3b] ($\Delta c\simeq -0.3$). However, the size of $\Delta c\simeq -5\cdot 10^{-4}$ given in [3d] is even smaller. Hence further investigation in this quantity is needed.

- Taking $\epsilon_c\simeq 0.06$, one has $\Delta c/\Delta\Sigma\simeq -0.02$. This is consistent with the prediction given in [3c], but smaller than that given in [3b]. Combining with the fractions of the light quark helicities, we have $\Delta u/\Delta\Sigma\simeq 2.17$, $\Delta d/\Delta\Sigma\simeq -0.99$, $\Delta s/\Delta\Sigma\simeq -0.16$, and $\Delta c/\Delta\Sigma\simeq -0.02$. One can see that the u-quark helicity is *positive* (parallel to the nucleon spin) and about two times larger than the total quark helicity $\Delta\Sigma$. However, the d-, s-, and c-helicities are all *negative* (antiparallel to the nucleon spin), and their sizes are decreased as

$$\Delta d\ :\ \Delta s\ :\ \Delta c\ \simeq\ 1\ :\ 10^{-1}\ :\ 10^{-2}. \qquad (19)$$

  Compare to the strange helicity Δs, the IC helicity is one order of magnitude smaller.

To summarize, we have discussed the IC contribution in the SU(4) quark meson model with symmetry breaking. Our results suggest that the probability of finding the IC in the proton is in the range $0.003\sim 0.019$, and the IC helicity is small and negative, $\Delta c\simeq -(0.003\sim 0.015)$. The fraction of the total quark helicity carried by the intrinsic charm is also small, $\Delta c/\Delta\Sigma\simeq -(0.007\sim 0.035)$.

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Tables

TABLE I: Quark Flavor Observables.

Quantity	Data	SU(4) [This paper]	SU(3) [6]
$\bar{d}-\bar{u}$	0.110 ± 0.018[12] 0.147 ± 0.039[13]	0.111	0.143
$\bar{u}/\bar{d}$	$[\bar{u}(x)/\bar{d}(x)]_{0.1<x<0.2} = 0.67 \pm 0.06$[12] $[\bar{u}(x)/\bar{d}(x)]_{x=0.18} = 0.51 \pm 0.06$[14]	0.71	0.64
$2\bar{s}/(\bar{u}+\bar{d})$	$< 2x\bar{s}(x) > / < x(\bar{u}(x)+\bar{d}(x)) >= 0.477 \pm 0.051$[15]	0.66	0.76
$2\bar{c}/(\bar{u}+\bar{d})$	–	0.083 ± 0.055	0
$2\bar{s}/(u+d)$	$< 2x\bar{s}(x) > / < x(u(x)+d(x)) >= 0.099 \pm 0.009$[15]	0.118	0.136
$2\bar{c}/(u+d)$	–	0.015 ± 0.010	0
$(s+\bar{s})/\sum(q+\bar{q})$	$< 2x\bar{s}(x) > / \sum < x(q(x)+\bar{q}(x)) >= 0.076 \pm 0.022$[15] 0.10 ± 0.06[16] 0.15 ± 0.03[17]	0.090 ± 0.001	0.103
$(c+\bar{c})/\sum(q+\bar{q})$	0.03 [4f]* 0.02 [2]* 0.01 [4e]* 0.005 [3a,3d]*	0.011 ± 0.008	0
$\sum\bar{q}/\sum q$	$\sum < x\bar{q}(x) > / \sum < xq(x) >= 0.245 \pm 0.005$[15]	0.230 ± 0.004	0.231

TABLE II: Quark Spin Observables

Quantity	Data	SU(4) [This paper]	SU(3) [6]
Δu Δd Δs	0.85 ± 0.04[18] -0.41 ± 0.04[18] -0.07 ± 0.04[18]	0.871 ± 0.009 -0.397 ± 0.002 -0.065 ± 0.000	0.863 -0.397 -0.067
Δc	-0.020 ± 0.004 [3c]* -0.3 [3b]* $-5 \cdot 10^{-4}$ [3d]*	-0.009 ± 0.006	0
$\Delta\Sigma/2$	0.19 ± 0.06[18]	0.200 ± 0.006	0.200
$\Delta\bar{u}$, $\Delta\bar{d}$	-0.02 ± 0.11[19]	0	0
$\Delta\bar{s}$, $\Delta\bar{c}$	–	0	0
$\Delta c/\Delta\Sigma$	-0.08 ± 0.01 [3b]* -0.033 [3c]*	-0.021 ± 0.014	0
$\Delta s/\bar{s}$	–	$-3/10$	-0.269
$\Delta c/\bar{c}$	–	$-16/51$	–
$c_\uparrow/c_\downarrow$	–	35/67	–
$s_\uparrow/s_\downarrow$	–	7/13	$\simeq 0.58$
Γ_1^p Γ_1^n	0.136 ± 0.016[18] -0.041 ± 0.007[10]	0.143 ± 0.002 -0.042 ± 0.001	0.142 -0.042
Δ_3 Δ_8	1.2670 ± 0.0035[11] 0.579 ± 0.025[11]	1.268 ± 0.010 0.605 ± 0.006	1.260 0.600